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# ANALYSIS OF EFFICIENCY AT A THERMAL POWER PLANT

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**Abstract** - ***In the existing scenario, most of the electricity produced throughout the world is from steam power plants. Therefore, it is very important to ensure that the plants are working with maximum efficiency. Thermodynamic analysis of the thermal power plant has been undertaken to enhance the efficiency and reliability of steam power plants. Most of the power plants are designed by the energetic performance criteria based on first law of thermodynamics only. The real useful energy loss cannot be justified by the fist law of thermodynamics, because it does not differentiate between the quality and quantity of energy. The present work deals with the comparison of energy and exergy analysis of thermal power plant stimulated by coal. Generally, it is predicted that even a small improvement in any part of the plant will result in a significant improvement in the plant efficiency. Factors affecting efficiency of the Thermal Power Plant have been identified and analyzed for improved working of thermal power plant.***

***The objective of this work is to use the energy analysis and exergy analysis based on the first law of thermodynamics and second law of thermodynamics respectively, to identify the locations and magnitudes of losses in order to maximize the performance of a 15 MW thermal power plant in a paper mill, to evaluate the boiler, turbine and condenser efficiencies. In order to improve the efficiency and performance of a plant, it is necessary to regularly check and estimate the efficiencies separately and periodically.***

***Key Words:*** *Energy efficiency, Exergetic efficiency, Exergy destruction, Energy loss*

## 1. INTRODUCTION

The most evident problem in this world is the reduction of non-renewable energy sources. Therefore, energy security is the major concern of today's world. Improving efficiency of the energy systems is an essential option for the security of future energy.

Every power plant losses their efficiency due to its continuous operation, age and many other reasons. Everything grows older with time. After years of operation, a plant will no longer be operating at best practice levels. Efficiency deteriorates. This reduction in efficiency causes an increase in the carbon dioxide emission. The optimizations of power generation systems are one of the most important subjects in the energy-engineering field. Due to the high prices of energy and the decreasing fossil fuel recourses, the optimum application of energy and the energy consumption management method is very important.

Most of the power plants are designed by the energetic performance criteria based on the first law of thermodynamics only. The real useful energy loss cannot be justified by the first law of thermodynamics, because it does not differentiate between the quality and quantity of energy. The present study deals with the comparison of energy and exergy analysis of thermal power plants stimulated by coal. Economics of power generation does not only require designing an efficient power plant, but also following proper operation and maintenance strategy such that the energy conversion efficiency of the plant throughout its life cycle remains high. Exergy analysis usually predicts the thermodynamic performance of an energy system and the efficiency of the system components by accurately quantifying the entropy-generation of the components.

The aim of this work is to calculate the overall thermal efficiency of the thermal power plant and analyze the thermodynamic performance of the components in the plant by using energy and exergy analysis.

## 2. DESCRIPTION ABOUT THE PLANT

In this plant, there are two 60 tones per hour coal fired AFBC boilers, one 21 tones per hour chemical recovery boiler and 15 MW extraction cum condensing steam turbine generator to meet power and steam requirements.

The Recovery boiler finds an exclusive application in paper mills. The basic purpose of the plant is to convert the raw materials, wood into paper. This involves a chemical process and the recovery boiler is used to recycle the same chemicals is minimized.

Pulverized coal (fed using coal feeders – 4 feeders per boiler) is used for producing steam from De-mineralized water. De-mineralization is done in De-mineralization (DM) Plant. In Atmospheric Fluidized Bed Combustion (AFBC) boilers, sand is heated from bottom side using diesel and furnace oil. Coal is fed to the hot sand and coal absorbs heat from the sand and burns which heats the water in the tubes lining the surfaces of the boiler and superheated steam of about 450-degree Celsius and a pressure of about 60 kg/cm$^2$ is fed to the common header and then fed to the turbine. Steam for processing is supplied to various plants by using a pressure-reducing valve. Because the boiler is designed to produce 60 kg/cm$^2$ pressure steam, which is in accordance with the design of the TG. The TG using at the company is Extraction Condensation type. The most required steam for processing is 3.5 kg/cm$^2$ steam, and the major part is obtained from the turbine extraction.

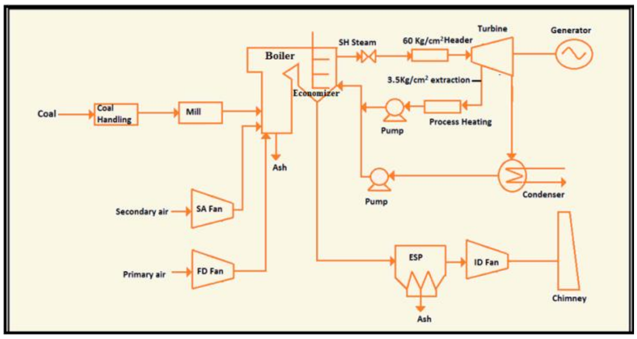


**Fig .1** Layout of Thermal Power Plant

## 2. OVERALL THERMAL EFFICIENCY OF THE PLANT

The three main components of a thermal power plant are boiler, turbine and alternator. Hence, the overall thermal power plant efficiency depends on the efficiencies of these three components. The thermal efficiency is an indication of how well the plant is being operated as compared to the design characteristics.

### *2.1 Boiler Efficiency Calculation*

Table 2.1: Various Data about Industrial Boiler

| PARAMETERS | UNIT | QUANTITY |
|---|---|---|
| Steam Pressure | bar | 60 |
| Enthalpy of feed water | KJ/Kg | 472.12 |
| Enthalpy of steam | KJ/Kg | 3231 |
| Mass Flow Rate of Fuel (Coal) | Kg/hr | 16200 |
| Calorific value of fuel (Coal) | KJ/Kg | 17793.9 |
| Mass Flow Rate of Fuel | Kg/hr | 5000 |

| | | |
|---|---|---|
| (Black liquor) | | |
| Calorific value of fuel (Black liquor) | KJ/Kg | 19677.96 |
| Steam flow from PB | Kg/hr | 83833 |
| Steam flow from RB | Kg/hr | 15080 |

Input heat content through coal = CV * coal consumption

$$= 17793.9 * 16200$$

$$= 80.072 MW$$

Input heat content through black liqour = CV * black liquor consumption

$$= 19677.96 * 5000$$

$$= 27.331 MW$$

Total input heat content = 80.072 + 27.331

$$= 107.403 MW$$

Output heat content of steam generated = Q * (H – h)

$$= 83833.33 * (3231 - 472.12) + 15080 (3231 - 472.12)$$

$$= 75.80 MW$$

$$\eta_{Boiler} = \frac{\text{output heat content}}{\text{input heat content}}$$

The efficiency of the boiler = 70.57%

*2.2 Turbine Efficiency Calculation*

The heat energy carried by the steam at high pressure and temperature is converted into mechanical energy by expanding. The pressure and temperature are lowered down after passing through the turbine.

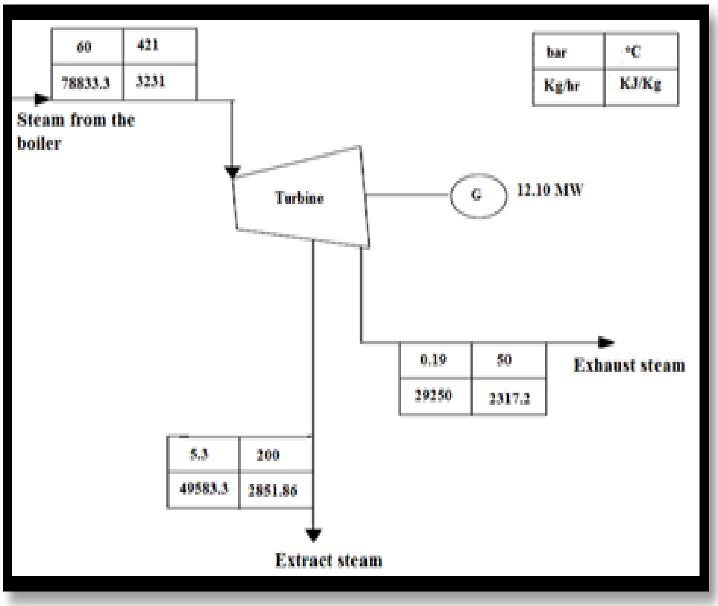


Fig 2.1: Various Data of a Turbine

$$\text{Efficiency of the turbine} = \frac{m_1h_1 - m_2h_2 - m_3h_3}{m_1h_1 - m_2(h_1 - h_2) - m_3(h_2 - h_3)}$$

Enthalpy of steam at turbine inlet = 3231KJ/Kg

Heat of steam at turbine inlet = mass flow * enthalpy

$$= 3231 * 78833.3$$

$$= 70.75 MW$$

Enthalpy of steam at turbine extraction = 2821.8KJ/Kg

Heat of steam at turbine extraction = 49583.3 * 2851.86

$$= 39.28MW$$

Enthalpy of steam at turbine exhaust = 2317.2KJ/Kg

Heat of steam at turbine exhaust = 29250 * 2317.2

$$= 18.83MW$$

$$m_1h_1 - m_2h_2 - m_3h_3 = 70.75 - 39.28 - 18.83$$

$$= 12.64MW$$

$$(m\_1\,h\_1 - m\_2\,(h\_1 - h\_2) - m\_3\,(h\_2 - h\_3) = 70.75 - 5.221 - 4.34$$

$$= 61.186MW$$

$$\eta_T = \frac{12.64}{61.186}$$

$$\eta_T = 21\%$$

*2.3 Generator Efficiency Calculation*

Normally the efficiency of electrical equipment is higher compared to mechanical components like furnace, boiler and turbine.

$$\eta_G = \frac{\text{Generator output}}{\text{Break output}}$$

$$= \frac{12.10}{12.64}$$

$$= 96\%$$

*2.4 Overall Efficiency*

One may expect the overall efficiency of a steam thermal power plant to be:

$$\eta_{Overall} = \eta_B * \eta_T * \eta_G$$

$$= 0.70 * 0.20 * 0.96 = 13.4\%$$

As far as modern power plant, the overall thermal efficiency is very less. For understanding the real problem in the plant, need an exergy analysis in every component.

| Sl no | Component | Efficiency (%) |
|---|---|---|
| 1 | Boiler | 70.57 |
| 2 | Turbine | 21 |
| 3 | Generator | 96 |
| 4 | Overall | 13 |

**3. Thermodynamic Analysis**

Engineers and scientists have been traditionally applying the First law of thermodynamics to calculate the enthalpy balances for more than a century to quantify the loss of efficiency in a process due to the loss of energy. The exergy concept has gained considerable interest in the thermodynamic analysis of thermal processes and plant systems since it has been observed that the First law analysis has been insufficient from an energy performance standpoint.

Energy analysis is based on the first law of thermodynamics, which is related to the conservation of energy. Second law analysis is a method that uses the conservation of mass and conservation of energy principles together with the entropy for the analysis, design and improvement of energy systems. Second law analysis is a useful method to complement, but not to replace energy analysis.

*3.1 Energy Analysis*

In an open flow system, there are three types of energy transfer across the control surface, namely working transfer, heat transfer and energy associated with mass transfer or flow. The temperature from the heat source and the work developed by the system are used for the analysis of open flow systems and to analyze plant performance whilst kinetic and potential energy changes are ignored. The energy or first law efficiency of a system is defined as the ratio of energy output to the energy input to the system.

$$\eta_i = \frac{\text{Desired output energy}}{\text{Input energy supplied}}$$

*3.2 Exergy Analysis*

It can specify where the process can be improved and therefore, it will signify what areas should be given consideration. The simple energy balance will not be sometimes sufficient to find out the system defect. In such circumstances, the exergy analysis is a well thought-out to be significant to locate the system's imperfections.

$$\eta_i = \frac{\text{Desired output energy}}{\text{Maximum possible output}}$$

*3.3 Boiler*

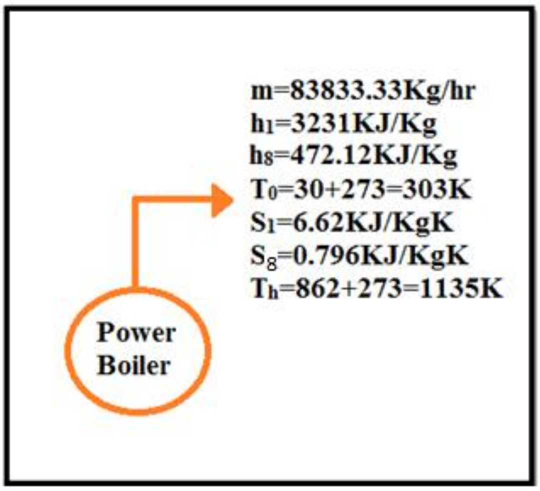


**Fig 3.3.1** Properties of Boiler

3.3.1 Energy Analysis

$$\text{Energy efficiency of power boiler} = \frac{\text{Steam produced} * (h - h_w)}{\text{Coal consumption} * CV}$$

$$= \frac{83833.33 * (3231 - 472.12)}{16200 * 17793.9}$$

$$= 80\%$$

Energy loss in boiler = input − output

$$= (16200 * 17793.9) - (83833.33 * (3231 - 472.12))$$

$$= 15826KW$$

3.3.2 Exergy Analysis

$$\Psi_{boiler} = \frac{\text{Exergy increase of steam}}{\text{Exergy of heat input}}$$

$$\Psi_{boiler} = \frac{m[(h_1 - h_8) - T_0(S_1 - S_8)]}{Q_{in}[1 - \frac{T_0}{T_h}]}$$

$$\text{Exergy increase of steam} = m[(h_1 - h_8) - T_0(S_1 - S_8)]$$

$$\text{Exergy increase of steam} = 83833.33[(3231 - 472.12) - 303(6.62 - 1.399)]$$

$$= 1176.917 * 83833.33$$

$$= 27406KW$$

$$\text{Exergy of heat input} = Q_{in}[1 - \frac{T_0}{T_h}]$$

Where,

$$Q_{in} = m(h_1 - h_8)$$

$$\text{Exergy of heat input} = 83833.3(3231 - 472.12)(1 - \frac{303}{1135})$$

$$= 47094.966KW$$

$$\Psi_{boiler} = \frac{27406}{47094} = 58.19\%$$

$$\text{Exergy destruction in boiler} = Q_{in}\,[1 - \frac{T_0}{T_h}] - [m[(h_1 - h_g) - T_0(S_1 - S_g)]]$$

$$= 47094 - 27406$$

Exergy destruction in boiler = 19688KW

*3.4 Turbine*

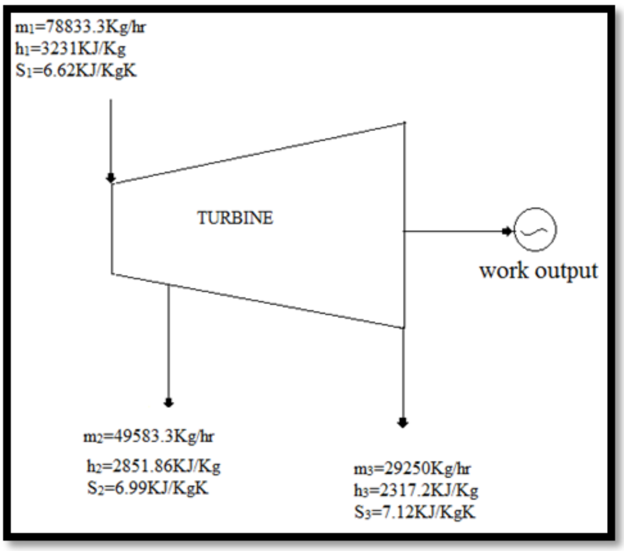


**Fig 3.4.1** Properties of Turbine

3.4.1 Energy Analysis

$$W_t = m_1h_1 - m_2h_2 - m_3h_3$$

$$W_t = 78833.3 * 3231 - 49583.3 * 2851.86 - 29250 * 2317.2$$

$$= 12.64MW$$

$$\text{Energy loss} = m_1h_1 - m_2(h_1 - h_2) - m_3(h_2 - h_3) - W_t$$

$$= 78833.3 * 3231 - 49583.3(3231 - 2851.86) - 29250(2851.86 - 2317.2) - W_t$$

$$= 48546.82KW$$

$$\text{Energy efficiency of boiler} = 1 - \frac{\text{Energy loss}}{m_1h_1 - m_2(h_1 - h_2) - m_3(h_2 - h_3)}$$

$$= 1 - \frac{48.55}{61.186}$$

Energy efficiency of boiler = 21%

3.4.2 Exergy Analysis

$$W_t = m_1h_1 - m_2h_2 - m_3h_3$$

$$W_t = 78833.3 * 3231 - 49583.3 * 2851.86 - 29250 * 2317.2$$

$$= 12.64MW$$

Exergy destruction can find out from exergy balance,

$$\text{Exergy destruction in turbine} = T_0\sigma$$

$$\sigma = m_2s_2 + m_3s_3 - m_1s_1$$

$$\sigma = 49583.3 * 6.99 + 29250 * 7.12 - 78833.3 * 6.62$$

$$= 9.16KWK$$

$$\text{Exergy destruction} = T_0\sigma = 9.16 * 303$$

$$= 2775KW$$

$$\text{Exrgetic Efficiency} = \frac{E_w}{E_m} = \frac{W_t}{W_t + E_d}$$

$$\text{Exrgetic Efficiency} = \frac{12.64}{12.64 + 2.775}$$

$$\Psi_{turbine} = 82\%$$

*3.5 Condenser*

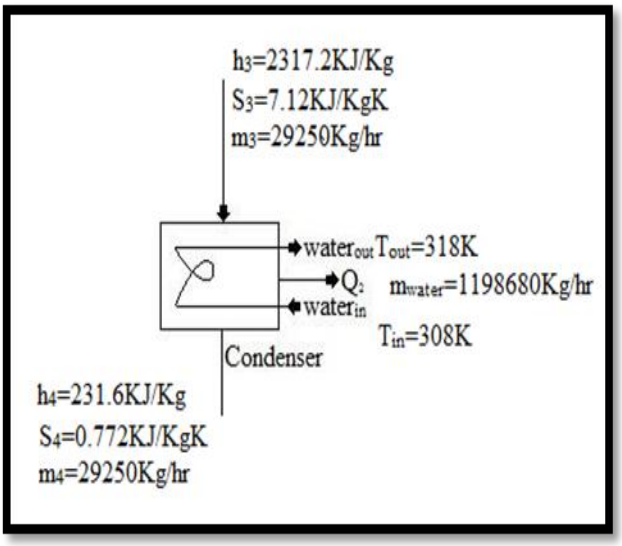


**Fig 3.5.1** Properties of a Condenser

3.5.1 Energy Analysis

$$\text{Energy efficiency of condenser} = \frac{m_{water} C_{pw} (T_{wo} - T_{wi})}{m_{steam} (h_3 - h_4)}$$

$$\text{Energy efficiency of condenser} = \frac{1198680 * 4.178(318 - 308)}{29250 * (2317.2 - 231.6)}$$

$$\text{Energy efficiency of condenser} = 82\%$$

$$\text{Energy loss} = \text{input} - \text{output}$$

$$\text{Energy loss} = 3034.15KW$$

3.5.2 Exergy Analysis

$$T_{wi} = 35°C = 308K$$

$$T_{wo} = 45°C = 318K$$

Exergy reduction of water

$$\varepsilon_{wo} - \varepsilon_{wi} = h_{wo} - h_{wi} - T_0 (s_{wo} - s_{wi})$$

$$= C_{pw} (T_{wo} - T_{wi}) - T_0 C_{pw} \ln \left(\frac{T_{wo}}{T_{wi}}\right)$$

$$= 4.178(318 - 308) - (303 * 4.178 * 0.032)$$

$$= 1.270KJ/Kg$$

Exergy reduction of steam due to condensation

$$\varepsilon_3 - \varepsilon_4 = (h_3 - h_4) - T_0(S_3 - S_4)$$

$$= (2317.2 - 231.6) - 303(7.12 - 0.772)$$

$$= 162.156KJ/Kg$$

$$\Psi_{condenser} = \frac{m_{water} (\varepsilon_{wo} - \varepsilon_{wi})}{m_{steam} (\varepsilon_3 - \varepsilon_4)}$$

$$\Psi_{condenser} = \frac{1198680 * 1.270}{29250 * 162.156}$$

$$\Psi_{condenser} = 32\%$$

$$\textit{destruction in condenser} = [m_{steam} (\varepsilon_3 - \varepsilon_4) - m_{water} (\varepsilon_{wo} - \varepsilon_{wi})]$$

$$= [(29250 * 162.156) - (1198680 * 1.270)]$$

$$= 894.64KW$$

## 4. CONCLUSIONS

Table 4: Comparison between First law efficiency and Second law efficiency

| COMPONENT | $\eta_i$ (%) | $\eta_{ii}$ (%) | Energy loss KW | Exergy loss KW |
|---|---|---|---|---|
| BOILER | 80 | 58.19 | 15826.41 | 19688.057 |
| TURBINE | 21 | 82 | 48546.82 | 2775 |
| CONDENSER | 82 | 32 | 3034.15 | 894.64 |

The efficiency of components in the power plant is found out by using energy and exergy calculation. From the above table we can see that the efficiency loss in boiler and turbine is more. Hence, we should improve the efficiency of boiler and turbine by proper maintenance. There are many factors, which influence the efficiency of the thermal power plant. The fuel used for combustion, type of boiler, varying load, power plant age, they lose the efficiency. Most of the loss in efficiency due to mechanical wear on variety of components, resulting heat losses. Therefore, it is necessary to check all the equipments periodically. Moreover, it is noticed that the overall efficiency of any thermal power plant depends upon the technical difficulties under unpredictable conditions.

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